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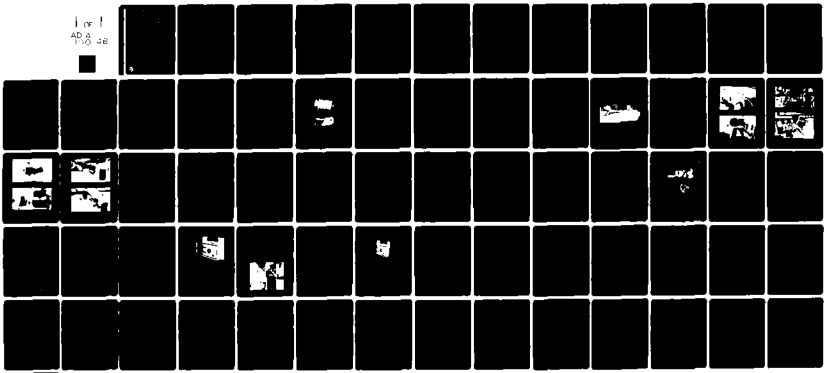

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FIELD EVALUATION OF BUILT-IN TEST EQUIPMENT (BITE) FOR VEHICLE OIL AND AIR CONTAMINATION

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No. MED125

By

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

A two-phase, three-year project has been completed to select and evaluate candidate commercially available Built-In Test Equipment (BITE) for monitoring diesel engine crankcase lubricant quality (Oil-BITE) and engine induction system air quality (Air-BITE) for use with Army Tactical and Combat vehicles. The screening criteria employed in the selection phase for both Oil-BITE and Air-BITE were found to be adequate for identifying primary candidate equipment items for field test. Operational

20. Abstract (Cont'd)

evaluation of Oil-BITE and Air-BITE equipment in a small, but representative sampling of tactical and combat vehicles at two major Army installations demonstrated that (a) the specific Oil-BITE equipment evaluated does not have potential for significant vehicle maintenance savings and (b) the Air-BITE equipment shows potential for sensing the presence of potentially harmful concentrations of sand and dust in vehicle engine air induction systems.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the technical and administrative assistance rendered by Mr. Robert L. Tannahill, Contracting Officer Technical Representative, U.S. Army Tank Automotive Command throughout the program, as well as Cpt. Robert W. Kocher, 2/5th Cavalry, 1st Cavalry Division, Ft. Hood, TX, CW3 Michael Tindol, 2/58th Infantry, 2nd Armored Division, Ft. Hood, TX, and Mr. Joe Geraci, Chief, Quality Assurance Branch, Ft. Lewis, WA for their assistance in supporting and monitoring the program. The authors also acknowledge the participation, encouragement and suggestions provided by Mr. A.A. Johnston of Southwest Research Institute.

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I. BACKGROUND

A. Army BITE Program

In spite of product improvements, modifications, etc., the air induction system has been for many years and continues to be a major maintenance problem in the M60 Main Battle Tank as described by the U.S. Army Material Systems Analyses Activity (AMSAA) in various Field Equipment and Technology Division reports and digests (1-3)*. Field reports showed an abnormally high failure rate for the AVDS-1790 series engines due to air filter overloading, induction system leakage, and other hardware malfunctions which permit excessive dust ingestion into the engine. Therefore, an Air-BITE (Built-In Test Equipment) device which could detect excessive dust/sand ingestion would serve as an early warning against engine degradation.

Oil-BITE would be used to supplement the present AOAP system by enabling motor pool personnel to monitor oil quality between normal AOAP samplings. Such action would assure rapid detection of degradation or contaminated crankcase oil.

B. Air-BITE

When engine air filters fail or intake air system leaks occur, dust and dirt are ingested by the engine, causing rapid wear in the bearings, cylinders, and cam areas. The resulting oil/dirt mix produces an abrasive grinding fluid which normal oil filtration cannot adequately remedy. A BITE device is needed to monitor the air entering the operating engine and to detect the presence of dust. When the concentration of dust exceeds the level expected for a properly functioning air filter system, the BITE should signal the vehicle operator that corrective action must be taken.

All commercial engine air filters permit passage of some dust under normal operation conditions. This normal dust level is in the range of 0.02 mg dust/ft^3. The Air-BITE should be responsive to levels above 0.02 mg dust/ft^3 within a reasonable period of time, thus eliminating false signals that would reduce the systems usability.

The BITE must also be responsive to a wide range of dust particle sizes which can be experienced in the field. Particles less than 3 micrometers would not be considered as harmful as those in the 3- to 25-micrometers range.

C. Oil-BITE

Oil quality in operating field vehicles is currently monitored by the Army Oil Analysis Program (AOAP) laboratories by sampling the lubricating oil of operational vehicles on a regularly scheduled basis and performing specific laboratory tests on those samples. These test results are then compared with the results of previous samples from the same vehicle, correlated with established guidelines and limits and corrective action is prescribed if the results fall outside acceptable standards. This procedure prevents premature engine

* Underscored numbers in parentheses refer to the list of references at the end of this report.

failure in many cases, but some failures occur because of rapid degradation of oil quality caused by overstressing of the oil. Rapid failure of the oil can occur shortly after routine sampling and analysis, and severe engine damage or failure can occur before the next scheduled oil sampling.

An Oil-BITE which would serve as an early-warning adjunct to the AOAP Lab analysis could save many "rapid" engine failures. When the oil begins to fail, an Oil-BITE could indicate such degradation, and an unscheduled sample could be sent to the AOAP Lab for confirmation and corrective action recommendations.

Monitoring of oil quality in tactical and combat vehicles is a difficult task due to the several factors influencing the properties to be monitored. These properties and some of the problem factors are:

1. Viscosity--A variety of problems must be considered when the lubricating oil viscosity is a criterion for its usefulness as a lubricant. The viscosity of oils supplied under MIL-L-2104C to the Army varies within a given grade because of normal specification max/min limits. As the oil temperature in the operating vehicle changes, especially during warmup, the viscosity of the oil will vary over a wide range. Different grades of lubricants are used in the vehicles depending on the climatic conditions, so the use of viscosity as a criterion for vehicle lubricant quality must be carefully employed to avoid false indications.

Other factors also influence the viscosity of the oil and must be considered. Fuel dilution or erroneous introduction of oil of a lower viscosity grade can reduce the oil viscosity and its ability to protect the rolling and rubbing surfaces. Oxidation thickening of the oil produced by stressing of the oil in service can increase the viscosity and limit the oils' cooling effects because of inadequate flow. Prolonged use can produce heavy soot loading and sludge buildup which can also increase the viscosity to unacceptable limits. Thus, an out-of-range viscosity measurement could indicate a variety of problems in the fielded vehicle but correlation of the measurement is difficult.

2. Acidity--Acids are produced by the combustion process and are introduced in the blowby gases to the crankcase. Organic acids are produced by high-temperature stressing of the oil. These acids deplete the alkaline additive package, and corrosive wear can result as the acidity of the oil reaches a point where metal attack can begin. It is very important to monitor oil acidity to avoid such corrosive wear.

3. Wear Metals--The wear metal content of an oil is an indication of corrosion, erosion, or mechanical failure of some key component. A built-in device would be very valuable if it could indicate the rate of wear. Since the rate of wear would be difficult to measure, total wear metal content would be of real value in indicating need for unscheduled oil sampling or draining.

II. OBJECTIVES

The objectives of this program were as follows:

- Investigate commercially-available Built-In Test Equipment (BITE) for monitoring (a) engine induction air for airborne contaminants and (b) engine oil condition.
- Provide technical support for procurement, laboratory evaluation, and analysis of commercial Air- and Oil-BITE devices to determine units suitable for field testing.
- Select one device for each application.
- Conduct realistic field evaluation of the selected BITE devices.

III. APPROACH

Candidate suppliers were identified and briefed on the objectives of Air- and Oil-BITE (4). Potential suppliers were informed that in order to complete the program in three years, a primary requirement was to use existing equipment with little or no redesign work. Of twelve companies identified and visited, seven were considered as potential suppliers. Three of these companies were considered prime prospects, and four were viewed as long-term alternate suppliers.

Laboratory testing was conducted at vendor laboratories under Southwest Research Institute (SwRI) supervision to determine the Air- and Oil-BITE candidate that would be best suited for field testing.

Initial procurement was made of twelve dust detectors and three oil analyzers for field testing at Ft. Hood, TX. The dust detectors were mounted in M60 and M113 vehicles. Two additional oil analyzers were procured as backup units for the ones being field tested, and twelve additional dust detectors were purchased and mounted on M60 vehicles at Ft. Lewis, WA.

IV. EQUIPMENT SELECTION

A summary of projected purchase volumes was required to present information to the potential suppliers. A search of the literature for commercial devices which might meet the requirements of the program was conducted, and the suppliers were contacted to determine interest and potential. The literature provided names of organizations which might be potential suppliers of BITE devices. The companies visited were:

- Beckman Instruments, Inc. Fullerton, CA - Oil/Air BITE
- Pall Corporation, Glen Cove, L.I., NY - Oil/Air BITE
- Donaldson Company, Inc., Minneapolis, MN - Air BITE
- Royco, Inc., Menlo Park, CA - Air BITE
- Harry Diamond Laboratories, U.S. Army, Silver Springs, MO - Oil BITE
- Kevex Corp., Foster City, CA - Oil BITE
- Norcross Corp., Newton, MA - Oil BITE
- Northern Instruments, Inc., Lino Capes, MN - Oil BITE
- Pitchford Scientific Instruments, Canonsburg, PA - Oil BITE
- Princeton Gamma-Tech, Princeton, NJ - Oil BITE
- Technical Development Co, (TEDECO), Glenalden, PA - Oil BITE
- Texas Instruments, Inc., Attleboro, MA - Oil BITE

Several smoke detector manufacturers were contacted for Air-BITE. Some of the commercially available smoke detectors have potential as dust detectors because they are optical in design, but no manufacturer was interested in participating in the Air-BITE program due to the relatively low volume of devices which would be purchased by the Army.

Briefing sessions were held with key engineering and marketing personnel of each company to outline the purpose, objectives, time frame, and the problem areas involved in the BITE program. Each company was given the option of participating in Air-BITE, Oil-BITE or both. The briefings also provided the opportunity for SwRI personnel to evaluate the companies' approaches, facilities, and capabilities to supply and support a BITE item. After allowing one to two weeks for consideration, marketing management was contacted by telephone to determine the level of interest of the potential supplier for BITE devices.

Prior to the actual testing of potential BITE candidates, TACOM personnel visited, reviewed, and planned the program activities. The BITE phase was discussed in detail, including respondents' approaches to meeting program requirements. Overall, the responses from industry and approaches available to meet both Air-BITE and Oil-BITE objectives were considered good, although Oil-BITE response could not be completely problem-solving because of the complexity of the multifaceted objectives.

Table 1 lists the potential suppliers for follow-up consideration. The first three were considered prime prospects. The other four were to be considered as long-term alternate suppliers.

TABLE 1. POTENTIAL BITE SUPPLIERS

Potential Suppliers	Type BITE
Donaldson	Air (Filter Type)
Royco	Air (Optical)
Northern	Oil (Dielect)
Texas Instrument	Oil (Acidity)
Tedeco	Oil (Mag. Chip)
Pall	Oil (Diagnos. Filt.)
Norcross	Oil (Viscosity)

In summary, the briefing and planning phases produced three prime candidates:

- The Donaldson filter-type dust detector
- Royco optical dust detector
- Northern Instruments' LUBE-SAFE handheld oil monitor

After review of the overall objectives, these three candidates were selected for more extensive and immediate testing. Details of this testing are given in the following section.

V. LABORATORY TEST PROGRAM

A. Air-BITE

1. Donaldson--Tentative test plans were made with the Donaldson Company to establish sensitivity and total contaminants level at which the Donaldson Dust Detector signals contamination. Tests were run at Donaldson under SwRI staff supervision. The equipment evaluated by Southwest Research Institute had been on the commercial market for two years in off-road usage.

This commercially available device was tested for repeatability, sensitivity, and response time. Donaldson Bulletin No. P45-7649 shown as Appendix A illustrates the detector and its positicn relative to the intake manifold or turbocharger inlet.

Test conditions were calculated based on the airflow rates expected in M60 and M113 vehicles. The dust detectors would be required to function from idle speed to full throttle in low and heavy dust environments. It was decided to test at near full throttle conditions when heaviest dust conditions could be expected. This corresponds to 675 SCFM for the Detroit Diesel 6V53 engine and 980 SCFM for the 6V53T engine used in the M113 vehicle. The M60 has two air induction systems, one for each bank of six cylinders, and the maximum airflow expected in each system is 600 SCFM. Airflow of 900 SCFM was chosen as the test condition maximum.

Dust levels during the test were difficult to select and control, especially at low concentrations. The dust to be used was AC Fine Test Dust, an industry standard. The efficiency of the air filters for either the M60 or the M113 is about 99 percent for new filters. As the filters become dirt-laden, the efficiency rapidly rises to approximately 99.9 percent. Dust-filled air is considered zero visibility at 25 mg dust/SCF. Thus, a new air filter in zero visibility dust could pass dust at the 0.25 mg/SCF level initially and still be functioning properly. Of course, at these levels, the filter will quickly load and become more efficient, reducing the amount of dust passed.

However, the total amount of dust the engine ingests creates the major damage and not the momentary high concentrations or pulses of short duration. Therefore, it was decided to test at various dust levels and determine the length of time required for indication of dust at each level and the total quantity of dust ingested at each level. The level of 0.39 mg/SCF was the lowest level that could be continuously fed and was 56 percent higher than the expected levels of 0.25 mg/SCF for a new filter in worst dust conditions.

The test facilities were capable of operating under controlled flow rate, controlled dust feed rate, and absolute filtration. The dust tunnel was approximately 12 feet long with a 3-foot diameter absolute filter. Special controls held the air flow at the preset selected value. The tunnel was operated at 918 SCFM of intake air and AC Fine Test Dust was fed to the air intake from a rotary table variable speed feeder. Times were measured for detector activations and total dust ingested was determined by weight increase of the absolute filter in the dust tunnel. The device was found to be repeatable at a given dust concentration. At the 0.39 mg/SCF concentration level, the response varied within 6 percent of the mean. It was found that at higher dust ingestion

rates, the sensitivity increases, thus warning of dust even more quickly. Table 2 summarizes these data.

TABLE 2. DETECTION LEVELS OF DONALDSON DUST DETECTOR

Concentration of Dust in Air Intake, mg/SCF	Total Dust Ingested Before Signal, gm
0.39	2.3
1.2	2.9
1.7	3.0
2.6	2.9
4.5	1.7
7.6	1.7
11.4	1.7

Sensitivity of the detector can be easily varied by the manufacturer; therefore one run was conducted, where, by tripling the diameter of one orifice in the sensor cell, the sensitivity was decreased by a factor of 9. From this single run, the sensitivity appeared to vary inversely to the area of exposed filter. Figure 1 illustrates the sensor cell and the arrow indicates the orifice to be changed if sensitivity changes are required.

Figure 2 shows elapsed time before indication (ETBI) as a function of dust concentration. From this figure, it can be seen that the ETBI of the detector decreases as the dust concentration increases and, in high dust conditions, was less than 10 seconds.

The DONALDSON Detector was determined to be effective and sensitive and was recommended for field testing by SwRI staff.

2. Royco--Royco had developed a prototype bench model of an optical dust detector which was examined and tested under the guidelines of SwRI. The device operated on the forward light scattering principle. The device contained an incandescent light source, a plastic focusing lens, and a photodiode sensor all mounted on an optical bench with appropriate light shields, baffles, and masks. The device was extremely sensitive and the 1- to 40-mV output was used to trigger the alarm indicator. Test facilities at SwRI were used for measuring the sensitivity range and repeatability of the device following inspection and training at Royco.

The device was very responsive to small particle dust in air. However, the dust to be detected is of larger particle size than 10 micrometers, and the detector lacked adequate sensitivity to these particles. A response of 7 mV for concentrations of 2 mg/SCF was typical. Noise levels and drift were of the order of 1 mV. The chief engineer of Royco indicated that a right angle scattering device would be more likely to provide the increased sensitivity of 10 mV for 0.05 mg dust/SCF required. The right angle device would probably be more simple in design, lower in cost, and easier to install.

Royco made the appropriate redesign, and conducted additional tests and calibration using a dust bench apparatus designed by SwRI. The modified detector was very sensitive to the size of dust expected in the field application, and the principle of the Royco device was shown to be effective. However, the cost was prohibitive as the detector is a very sophisticated device. Royco engineers be-

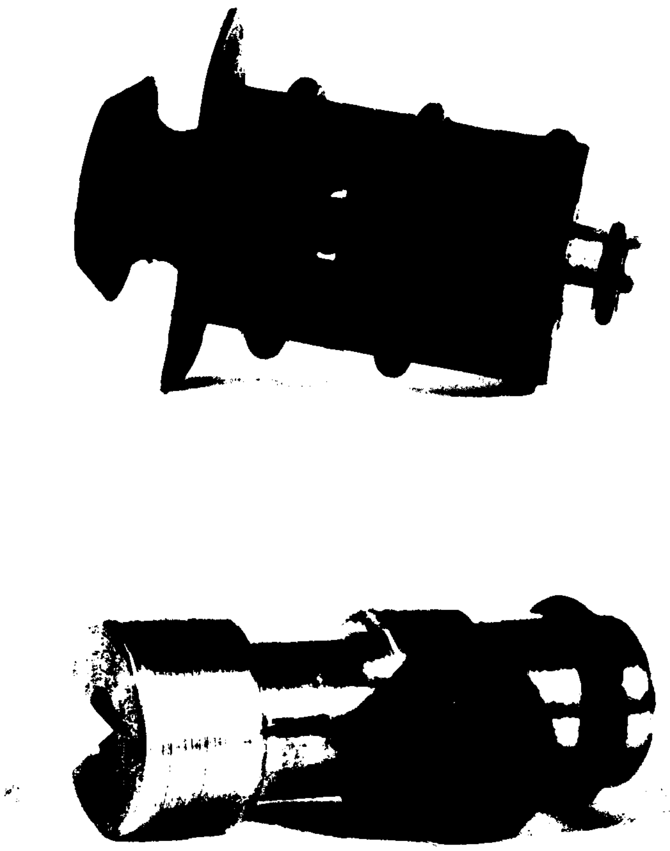


Figure 1. Sensor Housing and Cell for Donaldson Dust Detector

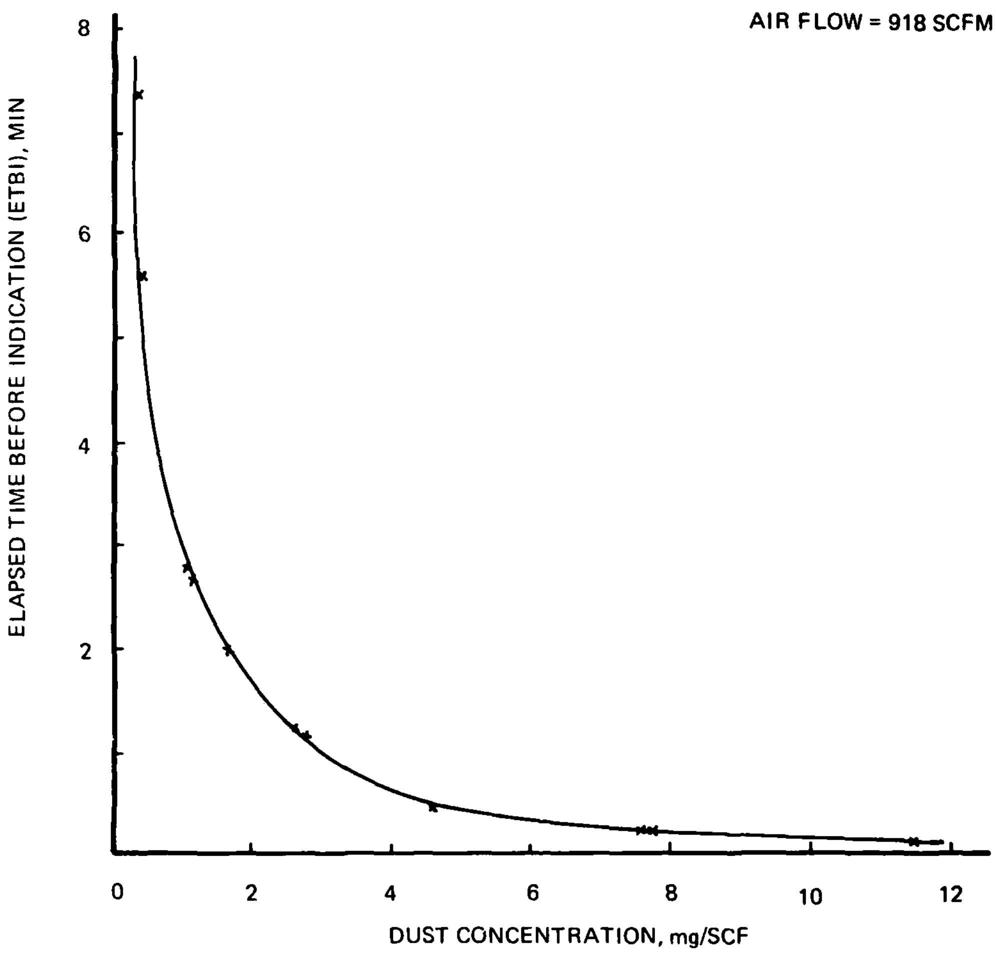


Figure 2. Response Time of Donaldson Dust Detector

lieve that the device can be redesigned from different materials and simplified to bring the cost into the range required.

This redesign would take significant time and money and was beyond the scope of the BITE program; therefore, Royco was dropped from consideration in this program.

B. Oil-BITE

Most of the potential suppliers for Oil-BITE requested samples of oil which exhibited the various problems previously described. Five gallons of a highly stressed used oil with nearly 50 percent increase in viscosity and a high acid number was obtained, analyzed, and made available to those respondents requesting a test sample. Norcross, Northern Instruments, and Texas Instruments received samples. An additional sample containing high wear metals was also provided to Northern, Pall, and Tedeco.

The results and responses from the potential suppliers are described as follows:

1. Northern Instruments--The along-side-the-vehicle oil tester (LUBE-SAFE) marketed by Northern Instruments Co. was laboratory tested, and its performance was similar to the larger, more sophisticated model from the same manufacturer. The larger model had been under test at the U.S. Army Fuels and Lubricants Research Laboratory (AFLRL) (located at Southwest Research Institute) for two years and had correlated satisfactorily with engine condition and chemical laboratory tests. The device measures the dielectric properties of the lubricant. The dielectric property decreases as oil contamination from soot, sludge, acid buildup, and wear metals increases. Fuel dilution causes an increase in dielectric constant, and oxidation of the oil causes the dielectric constant to decrease. Erratic meter readings (needle fluctuation) are indicative of lubricant contamination from a glycol coolant leak to the oil. The device does not distinquish which property is changing, merely that the quality of the oil is decreasing. Appendix B shows the operating manual of LUBE-SAFE.

After careful examination of the LUBE-SAFE device, both at the manufacturer's plant and SwRI, and after comparison with the previously tested Lubrisensor, the tester was used to test a series of selected oil samples. In every case, where the oil was contaminated or stressed to a severe level, the LUBE-SAFE, like its sister instrument, Lubrisensor, indicated a failure case. Based on these results, additional units were recommended for field testing.

2. Texas Instruments (TI)--Oil samples were shipped to TI for testing of the corrosion monitor, a device originally designed for water systems but with long-range potential as an oil corrosion (acidity) monitor. After several months, TI responded that they did not desire to participate in the test program.

3. Tedeco--This company's chip detector was responsive to high wear metals but since the detector does not detect other factors influencing oil quality, it was not considered adequate for field testing.

4. Pall--Oil samples were provided to Pall, but the cost and problems of filter removal, handling, and subsequent analysis were considered too great to warrant field testing.

5. <u>Norcross</u>--Oil samples were provided to aid in design of a true built-in viscosity monitor. The device could not be developed within the time frame of this program.

In summary, the Northern Instrument LUBE-SAFE analyzer, although not a built-in test device, was the only candidate which appeared to have potential for the field test phase.

VI. FIELD TEST PROGRAM

A. Test Sites and Equipment

Ft. Hood, TX was selected as a site for the field test of the BITE devices based on the large concentration of combat vehicles and close proximity to SwRI. Ft. Lewis, WA was selected in order to evaluate the Air-BITE device under different geographical and climatic conditions. The Director of Industrial Operations (DIO), Ft. Hood, was visited following initial coordination by TACOM. SwRI personnel briefed the DIO, Battalion Maintenance Officer (BMO), and Battalion maintenance technicians, on the program objectives and the devices to be tested. A commitment of full cooperation was offered by all personnel concerned. Table 3 shows vehicle data and location.

TABLE 3. TEST VEHICLES

Location	Type Vehicle	Engine SN	Vehicle SN
Ft. Hood, TX	M60	A0856	5437
Ft. Hood, TX	M60	A0189	2211
Ft. Hood, TX	M60	A0295	2888
Ft. Hood, TX	M60	A0412	5097
Ft. Hood, TX	M113	55457	SJ10287
Ft. Hood, TX	M113	6D32271	C1118
Ft. Hood, TX	M113	6D12750	C5107
Ft. Hood, TX	M113	6D35987	C2363
Ft. Lewis, WA	M60	A2546	2842
Ft. Lewis, WA	M60	9793	4201
Ft. Lewis, WA	M60	A0280	3707
Ft. Lewis, WA	M60	A07773	4254
Ft. Lewis, WA	M60	A0251	4323
Ft. Lewis, WA	M60	A2568	3257

1. Test Vehicles--Air-BITE Installation--The vehicles to be employed in field test, especially for the Air-BITE, were the M60 tank and the M113 armored personnel carrier. Ft. Hood has a large number of both of these vehicles in operation. Plans were made to equip four M60's and four M113's with Donaldson Dust Detectors. Figure 3 shows an M60 to be equipped with a pair of detectors. The detectors had to be mounted in the duct work between the intake air filters and the turbocharger of the engine. This required special fabrication of duct work and hose connecting flanges to securely mount the detector and retain some flexibility of the duct system.

The flexible intake air ducts from both an M60 tank and an M113 personnel carrier were obtained for engineering review and installation of the Donaldson Dust Detector. A design conference was held at Donaldson to determine the configuration of the detector-duct work assembly for both types of vehicles to be included in the field test. It was decided that it would be best for Donaldson to assemble the dust detector in the duct work to simplify installation in the vehicles. The M113 system involves a section of metal duct with a "hump hose" (a flexible connector manufactured by Donaldson) as a connector on each end. The metal duct supports and contains the dust detector.

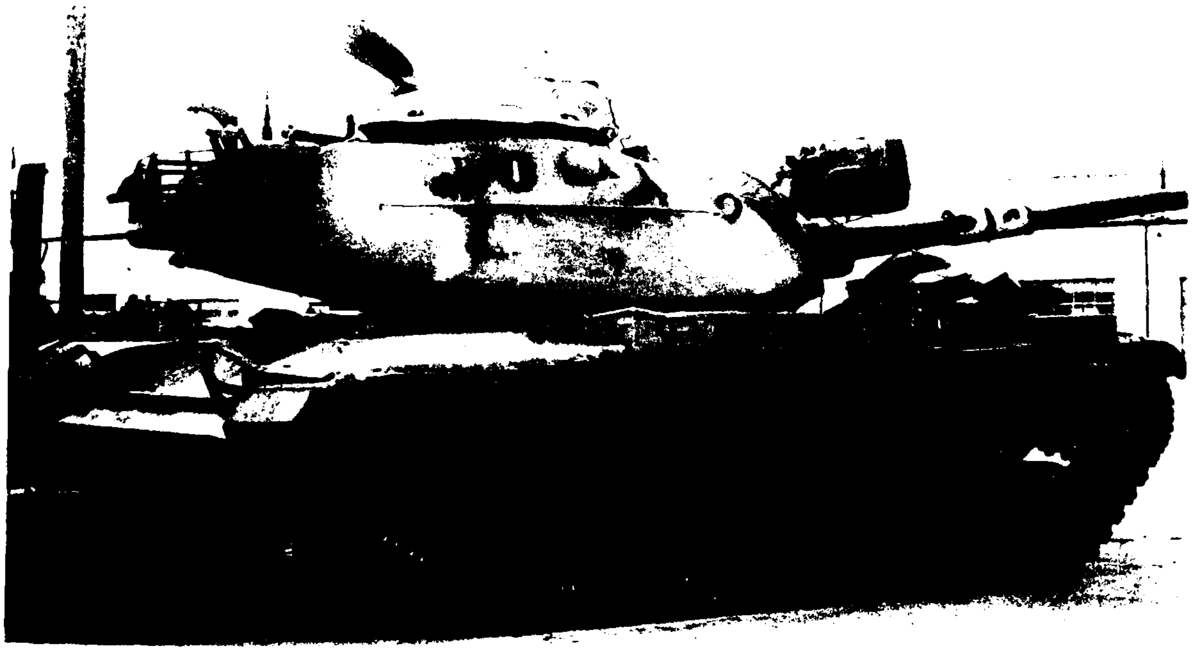


Figure 3. M60 Tank

The M60 installation was somewhat more difficult since the air ducts have metal flange connectors and clamps installed as an integral part. Donaldson personnel visited Ft. Ripley, MN to determine the precise position for locating the detectors on the M60. Donaldson also contacted the current manufacturers of the air duct and obtained the ducts directly from the factory so that Donaldson could do the custom fabrication, detector installation, and testing to assure that there was no effect on sensitivity. Four single assemblies for the M113 and four dual assemblies for the M60 were obtained.

The dust detectors for the M113 were delivered to Ft. Hood, but the units could not be fitted into the available space and required modification. Each unit required custom modification because of variation in the angular position of the air filter housing on each M113. Significant variation in air filter housings and installation positions is common on M113's according to DIO shop personnel. The custom fitting required rather involved cutting and rewelding of the metal tubing which supported the dust detector to align the tube between the air filter and the air intake elbow of the engine in close enough spacing to allow hose coupling with clamps. Figures 4 and 5 are photographs of dust detectors installed on different M113 vehicles. Note the variations required in installation for the different vehicles. Figures 6 and 7 show the location of the signal box in the operator's area of the M113.

Similar installation difficulties were encountered on the M60 because the delivered ducts were too short. Extensive modification were required to obtain a "good fit" of the duct-mounted detector in the limited space available. Figure 8 shows how the flanged elbow required lengthening and realigning. Figure 9 shows the completed duct as modified. Figure 10 shows the duct with detector in the mounting position to the turbocharger, and Figure 11 shows the accessibility of the sensor in the detector.

At Ft. Lewis, the Air-BITE device was installed by making a 3-inch cut in the original flex hose, the dust detector venturi was then inserted into the cavity and sealed with the two rubber gaskets provided in the installation kit.

2. Oil-BITE Analyzers--The Northern Instruments LUBE-SAFE was selected for field applications testing at Ft. Hood, TX. Even though this instrument is not a built-in test device, the principle of operation showed promise and a possibility exists for a built-in device in the future. *In any event, the tester is intended as an AOAP adjunct and not an AOAP replacement.*

B. Air-BITE Field Test

The work accomplished entailed the testing of the Donaldson dust detector installed on four M113 armored Personnel Carriers, four M60 Main Battle Tanks at Fort Hood, TX and six M60 Main Battle Tanks at Fort Lewis, WA.

The objectives of the test were to determine:

- device reliability
- effectiveness in detecting dust
- correlation of AOAP laboratory data on silicon content in the vehicles engine lubricant with dust sensing activations
- ease of maintainability

Figure 4. Donaldson Dust Detector
Installed on M113 Vehicle C-11

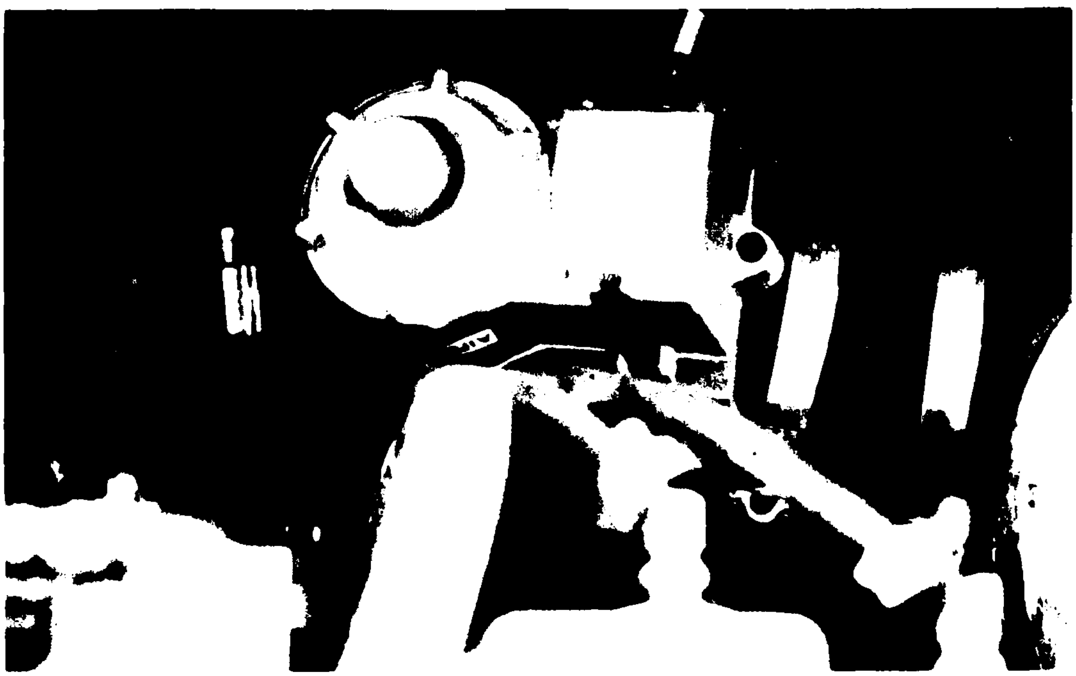


Figure 5. Donaldson Dust Detector
Installed on M113 Vehicle C-13

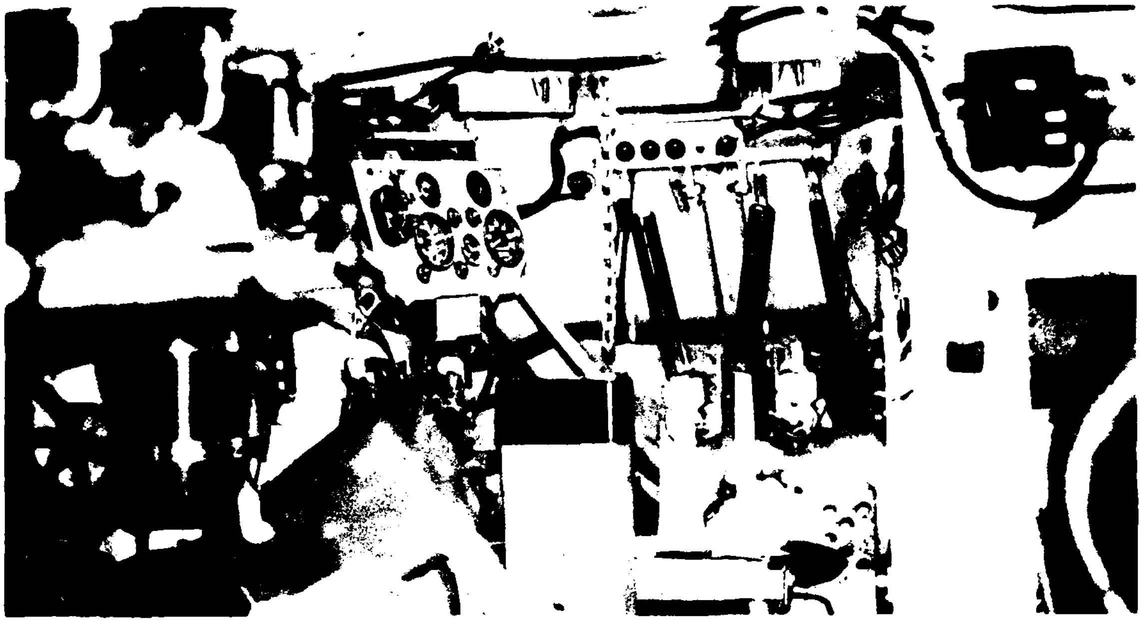


Figure 6. Overall View of M113 Operator Station
With Installed Signal Box

Figure 7. Closeup View of M113 Operator Station
With Installed Signal Box

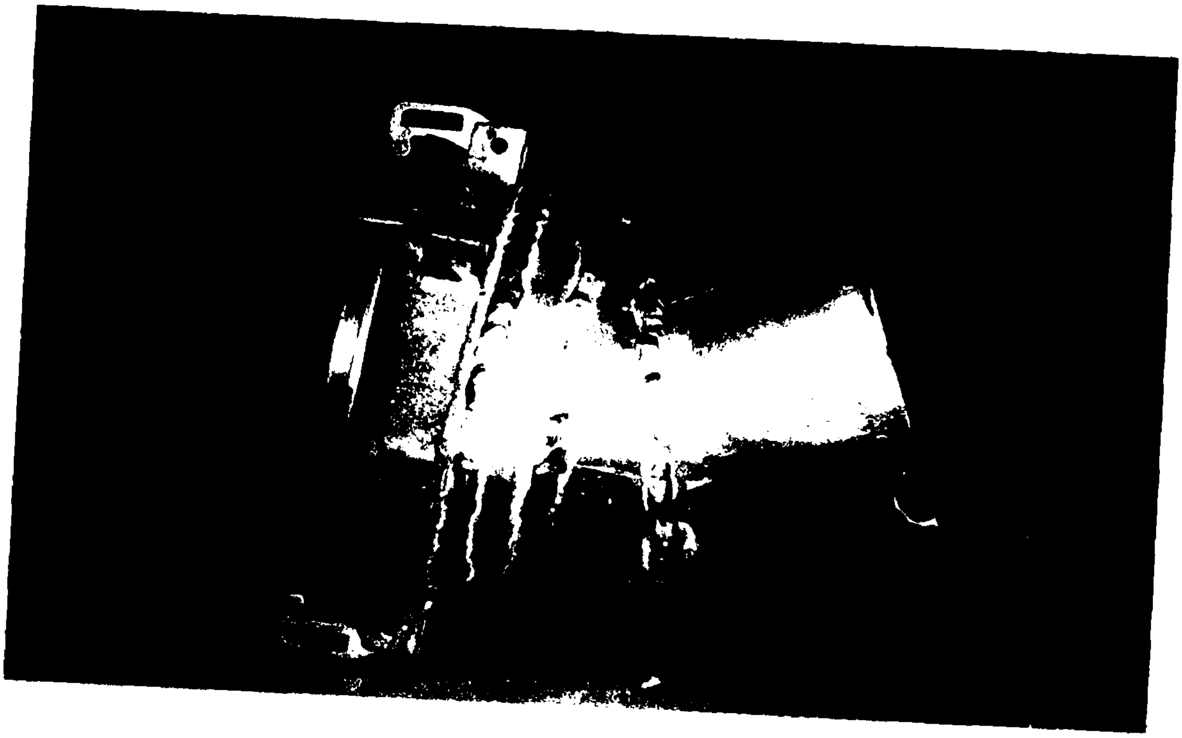


Figure 8. Modified Flange and Elbow For Dust Detector Installed on M60 Vehicle

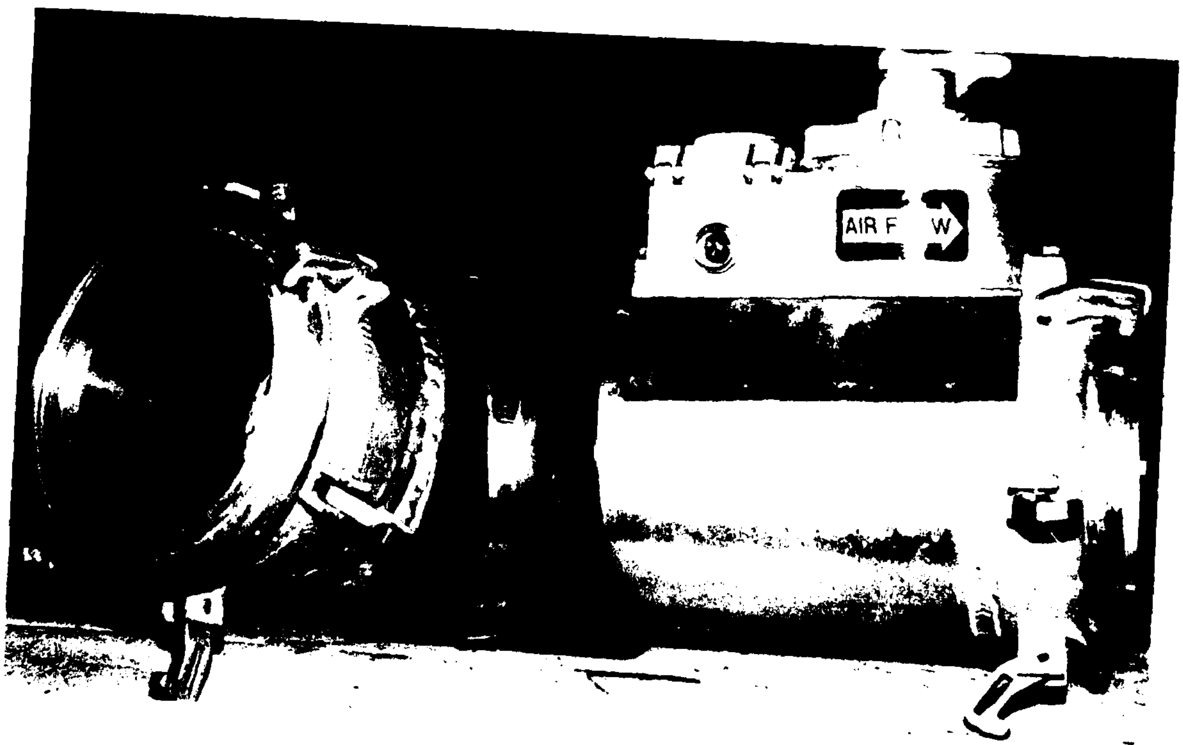


Figure 9. Complete Duct With Detector For M60 Installed

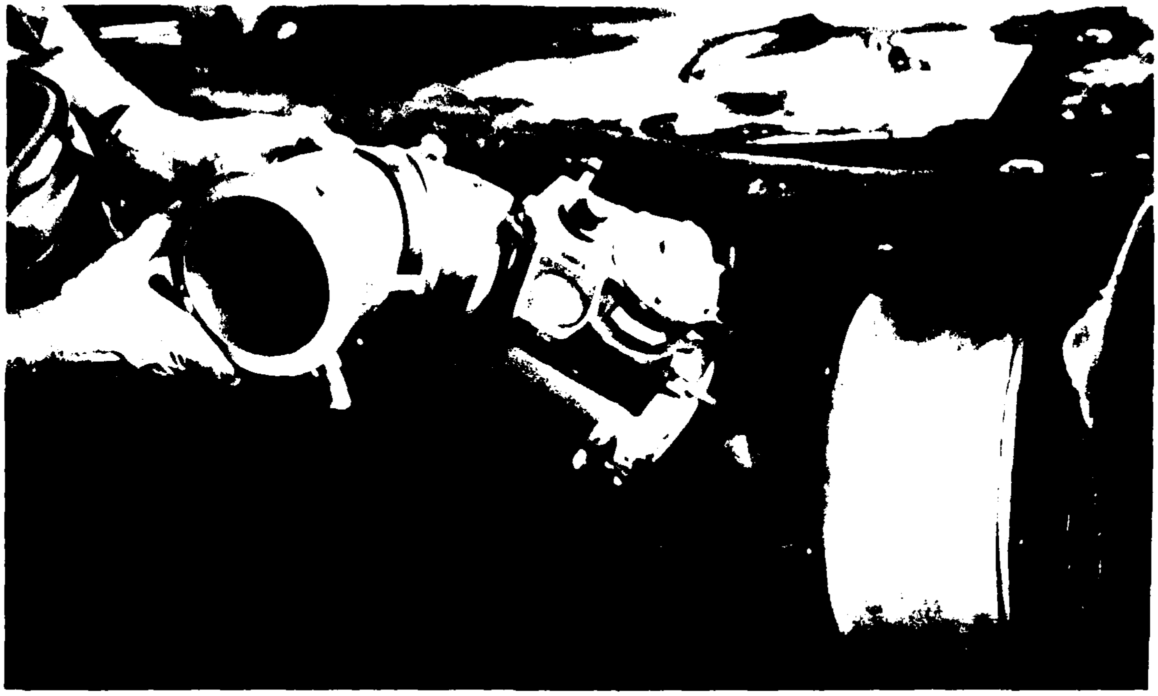


Figure 10. Duct With Dust Detector in the Installed Position On M60

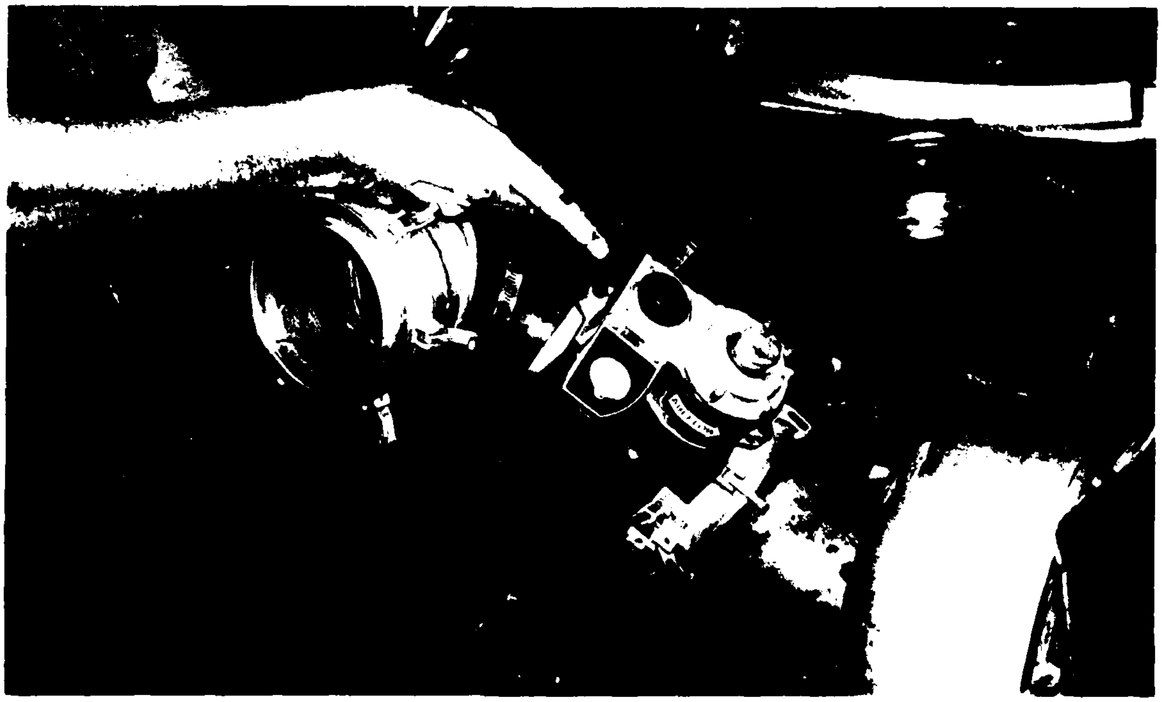


Figure 11. Sensor Access On Dust Detector

After the vehicles were fitted with dust detectors, each was to be operated as prescribed by unit operational requirements under normal operating conditions. The vehicle crews were only required to troubleshoot the dust detector systems and replace the sensor elements. The DIO Maintenance Division was responsible for mechanical and electrical repairs on the systems. A copy of the Air-BITE test plan and procedure, which designates assigned responsibilities, is found in Appendix C.

Crew responsibility upon dust detector activation was to record the date, hour reading, mileage, sensor replacement, and corrective action required. Such action would consist of visually checking the air intake system for damage, bent air cleaner, broken or damaged pipes, cracked or loose hose connections and clogged air filter.

In addition to determining the effectiveness of the dust detector, it was also desirable to determine if dust detector activations had a direct effect on the level of silicon in the engine oil. Therefore, an oil sample was taken at the time of activation and sent to the AOAP laboratory. Initially, this could not be accomplished due to the decentralized assignment of the vehicles. Oil samples were being taken; however, not all were reaching the AOAP laboratory in a timely and coordinated manner. To correct this situation, the test vehicles were centralized in one platoon. A significant advantage in doing this was that the vehicles would operate in the same area while on field exercises and one platoon leader would have operational control of the four test vehicles; thereby ensuring the crews complied with all test procedures. In addition, four like vehicles were selected, inspected, and designated as control vehicles. The test and control vehicles were operated in like field environment and terrain for approximately the same duration and mileage.

The expected flow rate at full throttle for an M60 tank is 600 SCFM from each of the two six-cylinder banks. Driving characteristics of the M60 tank are that in a start/stop cross-country operation it can be expected to operate near full throttle for extended periods. It is during these driving conditions that the dust concentration is expected to be the heaviest. The detectors were reliable and effective in detecting dust at varied flow rates. These observations were made from personnel monitoring activities during field exercises.

A detailed comparison of the AOAP laboratory's analyses of silicon levels expressed in parts per million was made on the four test and four control vehicles. The comparisons are based solely on silicon analyses conducted by the AOAP laboratory at Fort Hood, TX. The results of all the oil samples submitted on the test and control vehicles and analyzed by the laboratory from 1 April to 31 July 1980 are depicted in Figures 12 and 13. As evidenced by Figure 12, with the exception of vehicle C-20, all the test vehicles operated well below the marginal range of silicon level established by TM38-301-1 (Joint Oil Analysis Program Laboratory Manual for Nonaeronautical Equipment). The control vehicles, however, as seen in Figure 13, operated in the marginal, high, and abnormal range for several days within the 4-month period. Also, all the control vehicles required AOAP-directed oil changes while in the test vehicles only vehicle C-20 required an oil change. *It should be noted that vehicle C-20 operated with an undetected air induction leak before and after the span of time depicted in the graph. As can be seen in Figure 12, this vehicle's behavior was far more aberrant than the other three vehicles.*

It is the total amount of dust ingested by the engine that does the damage and not the momentary high concentrations or pulses of short duration.

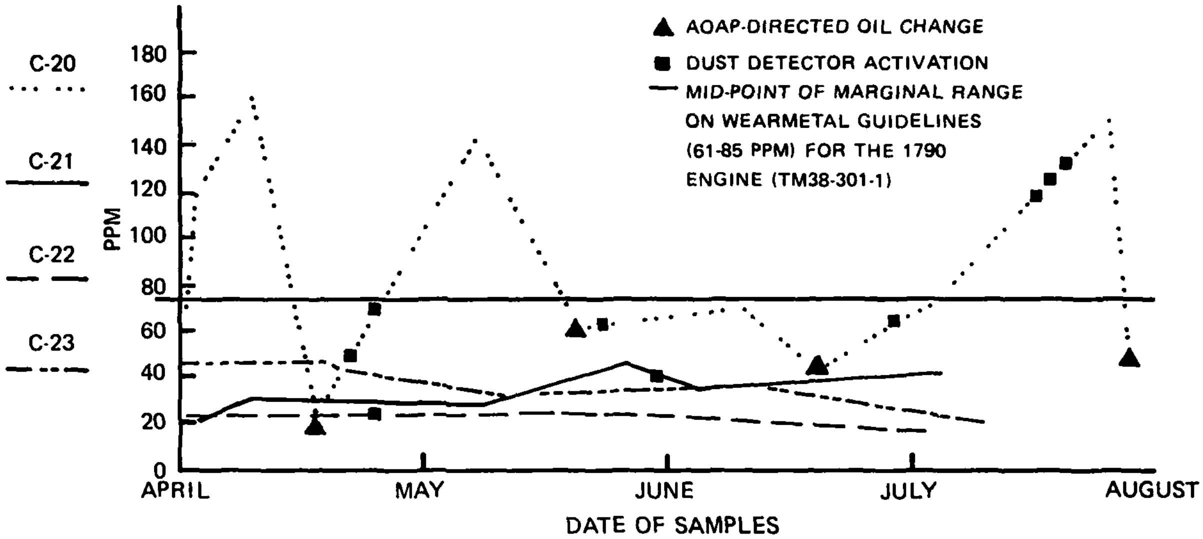


FIGURE 12. SILICON ANALYSIS FOR M60 TEST VEHICLES

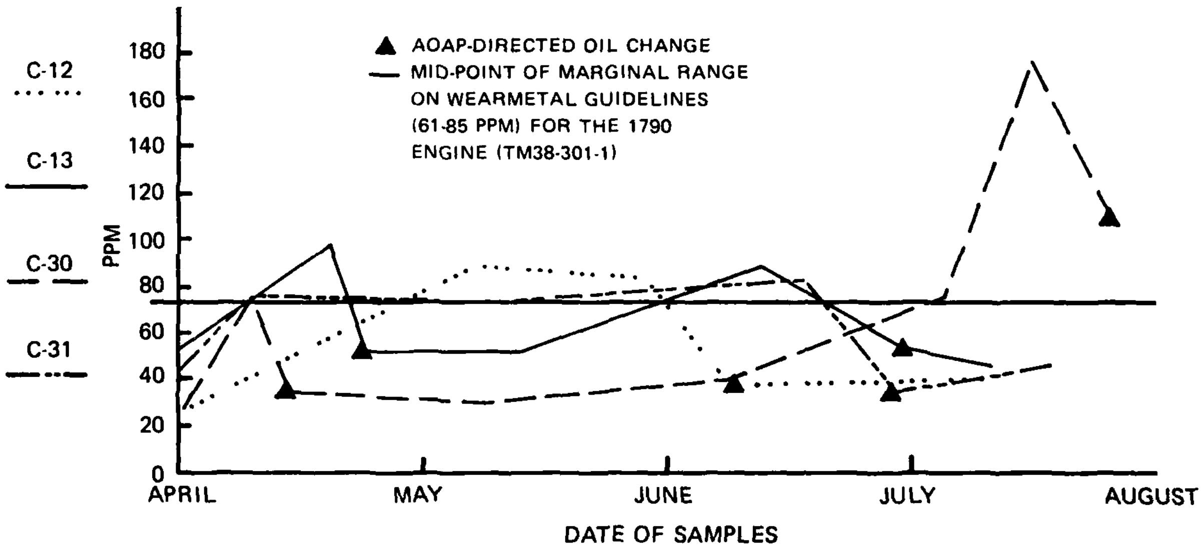


FIGURE 13. SILICON ANALYSIS FOR M60 CONTROL VEHICLES

In the case of vehicle C-20 in which the dust detector continued to activate and the problem went undetected, the number of activations did in fact have a direct effect on the engine lubricant silicon level. On the other hand, vehicle C-21 depicts an activation while the silicon level is falling. This in all probability is due to replenishing of engine lubricant causing a decrease in silicon level. Vehicle C-22 shows an activation and no apparent change in silicon level. Therefore, it can be deduced that an activation, per se, will not have an effect on the engine lubricant silicon level if effective corrective action is taken when the activation occurs.

The engine on vehicle C-20 failed on 2 September 1980, shortly after the comparison test. Cause of failure was attributed to a faulty air induction system. Based on the number of dust detector activations (Figure 12), if proper corrective action had been effected, the damage to the engine could have been prevented. Appendices D and E reference the cause of failure.

The Donaldson Dust Detector is a commercial device that was modified by the Donaldson Company to be adaptable to the M60 and M113 vehicle air induction systems. Further modifications were required by the DIO Maintenance Division to ensure a proper fit. Because the installation lacked the ruggedness required in a combat vehicle and lack of training on the part of the tank crews, maintainability was a problem throughout the test. Excessive equipment downtime was experienced due to these two factors. Examples of the above are: electrical wires and connectors damaged when removing powerpacks for quarterly services; detector system has a failsafe feature that, when electrical continuity is interrupted, the light in the control box in the driver's compartment comes on; consequently, control boxes were damaged from tampering when after sensor replacement, the light would not go off; aluminum flanges were damaged by disconnecting and connecting the dust detector hoses and clamps.

Only two activation events were recorded on the M113 test vehicles. One activation was caused by a broken electrical wire and the other was due to a clogged air filter. The AOAP laboratory did not make one recommendation due to silicon level on any of the M113 vehicles. Test results indicate that the M113 vehicle does not experience a dust ingestion problem as does the M60.

The vehicles at Fort Lewis, WA were not utilized as expected due to conditions after Mt. St. Helen's eruptions. However, there appears to be no variation in the performance of the dust detector due to geographical and climatic differences between Fort Hood, TX and Fort Lewis, WA.

One engine failure occured on 17 September 1980 at Fort Lewis, WA on vehicle B-34 during tank gunnery exercises at Yakima Firing Range. The dust detector did not activate prior to the failure. In checking the AOAP laboratory's oil analysis record, it was found that the vehicle had been operating with silicon levels in the high and abnormal range for several months prior to the installation of the dust detectors. There is no record of an oil sample at the time of failure; however, the sample processed prior to the engine failure was 89 PPM of silicon. Therefore, the possibility exists that the damage was caused by the silicon content already present in the engine lubricant and not by the ingestion of dust at the time of failure.

C. Oil-BITE Field Test

Between 200 to 400 vehicles were scheduled to be monitored by Fort Hood personnel. However, soon after the program began, it was learned that this

could not be possible due to the unit's changing weekly commitments. Therefore, 185 vehicles were identified for sampling, and the remainder were randomly picked. The Oil-BITE test plan is found in Appendix F.

Arrangements were made to obtain any unscheduled oil drain samples detected by the device so that detailed laboratory data correlation of tester readings and actual oil conditions could be established. Likewise, coordination with the Fort Hood AOAP Laboratory was made to provide a third-party source since the laboratory monitors combat vehicles (M60, M113) oil condition on a monthly schedule.

Key personnel at Fort Hood were trained in the use of the analyzers and began using the units to determine the optimum procedure for record keeping and reporting. SwRI requested the following information: the number of tests performed, and the number of "bad" oil readings with the analyzer. After a "bad" reading was indicated, samples of the oil were to be sent to Fort Hood AOAP laboratory for analyses. These data provided initial baseline information. After several attempts to obtain valid data from field personnel, it was apparent that in order to obtain data under controlled conditions the LUBE-SAFE Analyzer field evaluation program would have to be reorganized with a new test plan. The revised plan enabled SwRI personnel to collect all samples, make the necessary tests, and compare results with the AOAP laboratory. The selected vehicles were sampled by SwRI personnel on a bi-monthly basis and both LUBE-SAFE tests and the AOAP laboratory's data were carefully coordinated by SwRI personnel.

A total of 1020 used engine oil samples extracted from M60 and M113 vehicles at Ft. Hood, TX were analyzed utilizing the Northern Instruments Corporation LUBE-SAFE Analyzer. The lubricant that was used for the calibration of the analyzer was taken from unit stocks of MIL-L-2104C OE/HDO 30 seasonal lubricant. Of these total samples tested with the LUBE-SAFE Analyzer, 916 were rated as satisfactory and 104 were unsatisfactory. However, when these samples were analyzed by the AOAP laboratory, 1006 were satisfactory and only 14 were unsatisfactory. The fail index for the LUBE-SAFE was 10.19 percent as compared to the AOAP laboratory's fail index of 1.37 percent. This disagreement is considered to be unacceptable. It should be noted that in order to ascertain a correct LUBE-SAFE reading, in most cases, the oil samples were tested using three analyzers. The disparity in comparison between the LUBE-SAFE Analyzer and the AOAP laboratory can be attributed to two factors:

- *The AOAP laboratory's standard on fuel dilution is 3 percent; consequently, any sample with 3 percent or less fuel would receive a rating of satisfactory while the LUBE-SAFE fuel dilution standard was 1 percent.*

- *The LUBE-SAFE analyzer must be calibrated with a sample of unused lubricant of the same base stock as the lubricant being tested.*

Since different manufacturers supply lubricant to the military, the possibility always existed that the lubricant used to calibrate the analyzer was from a different manufacturer than the lubricant being tested; therefore, the reading on the LUBE-SAFE scale would be inaccurate.

Table 4 summarizes comparison between the LUBE-SAFE Analyzer and the AOAP laboratory.

TABLE 4. COMPARISON OF LUBE-SAFE ANALYZER AND AOAP LABORATORY DATA

Lubricant	Number of Samples Analyzed	LUBE-SAFE		Fail Index*	AOAP Lab		Fail Index*
		Sat	Unsat		Sat	Unsat	
MIL-L-2104C, OE/HDO30	1020	916	104	10.2%*	1006	14	1.4%

* Fail Index = $\frac{\text{Unsat}}{1020}$ x 100, %

VII. CONCLUSIONS

A. Air-BITE

On the basis of tests performed at Ft. Hood, TX and Ft. Lewis, WA, the following conclusions can be reached on the Donaldson Dust Detector:

1. The dust detector is responsive to the wide range of dust particle sizes which can be experienced in the field and is fully capable of sensing the presence of sand and dust in the air induction system of the M60 vehicle.

2. The detector is an effective early warning device that, if properly operated and maintained, can reduce premature engine failures.

3. The dust detector mount in its present commercial design is not compatable with the ruggedness of the M60 vehicle nor does it offer the flexibility required for ease of removal and installation by the tank crew.

B. Oil-BITE

The following conclusions can be reached based on results of tests conducted utilizing the Northern Instruments Corporation LUBE-SAFE Analyzer Model NI-3.

1. Because of its sensitivity to fuel dilution as opposed to AOAP laboratory fuel dilution standards (1 percent and 3 percent, respectively), and because of its reference lubricant calibration requirement, the LUBE-SAFE Analyzer does not warrant adaptation as an early warning adjunct to the AOAP laboratory.*

2. The LUBE-SAFE Analyzer meets all the manufacturer's specifications and can be an asset in fleet operations where a *single lubricant formulation is used and the reference lubricant used to calibrate the instrument is exactly this same formulation.*

---

* Personnel at Northern Instruments were contacted to determine if the sensitivity of the analyzer could be changed to correlate with the AOAP lab's standard of 3 percent. Northern offered two alternatives:

(1) the analyzer's sensitivity to fuel dilution can be changed to a higher percentage; however, if this is done it will also alter the instrument's sensitivity to the dielectric constant in the lubricant.

(2) to modify the analyzer by installing a linear scale with the absolute zero in the center and graduated readings to the left and right of center. Values would then be assigned to interpret the quantities of fuel and other contaminants in the lubricant.

Neither of these two alternatives is recommended because one alters a very important feature of the analyzer and the other nullifies the simple "GO-NO-GO" capability which is necessary for field applications.

VIII. RECOMMENDATIONS

A. Air-BITE

If the Donaldson Dust Detector is to be considered as a viable adaptation to the air induction system of the M60 tank, the following recommendations are made to improve durability and performance:

1. The dust detector mount and the signal control box should be of a military design and fully compatible with the rest of the components in the M60 tank.

2. The dust detector mount design should offer original part flexibility for ease of removal and installation.

3. Electrical wiring should be incorporated in the tank's main wiring harness rather than its present fuze-connected adaptation.

4. The electrical cable from the signal control box to the switch housing should be of heavier gage wire and have a quick disconnect adapter at both ends.

B. Oil-BITE

The concept of having an Oil-BITE which would serve as an early warning adjunct to the AOAP laboratory analysis could in fact save many engine failures; therefore, it is recommended that further investigation continue in the area of Oil-BITE.

It is not necessary for an Oil-BITE to readily identify contaminants nor to place a numerical value on findings as does the AOAP lab, but it is necessary for the instrument to correlate with the AOAP lab guidelines on oil degradation.

IX. LIST OF REFERENCES

1. R&D Field Liaison Division, U.S. Army Materiel Systems Analysis Activity Digest #2, May 1977.

2. Field Equipment and Technology Division, U.S. Army Material Systems Activity Digest #4, November 1979.

3. Ferrara, P.B. and Zearfoss, R.J., "An Evaluation of the M60 Series Tank Air Induction System," Reliability and Maintainability Division, U.S. Army Material Systems Analysis Activity, Interim Note No. R-76, February 1980.

4. Newman, F.M., "Evaluation of Commercial Induction Air Monitors and GO/NO-GO Oil Quality Testers as Built-In Test Equipment (BITE), Southwest Research Institute Interim Report No. MED106, AD A007213, August 1979.

APPENDIX A

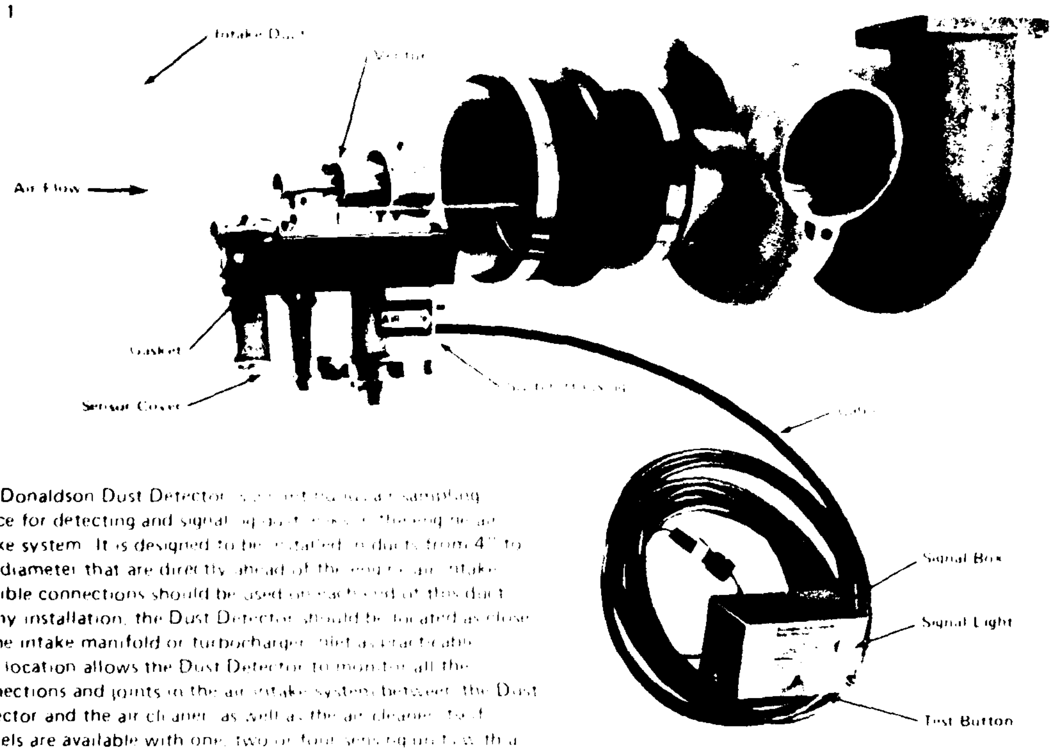
TECHNICAL DATA - DONALDSON DUST DETECTOR

donaldson

installation instructions

Donaldson Dust Detector

Fig 1



The Donaldson Dust Detector [illegible] sampling device for detecting and signaling dust leaks in the engine air intake system. It is designed to be installed in ducts from 4" to 10" diameter that are directly ahead of the engine air intake. Flexible connections should be used on each end of this duct. In any installation, the Dust Detector should be located as close to the intake manifold or turbocharger inlet as practicable. This location allows the Dust Detector to monitor all the connections and joints in the air intake system between the Dust Detector and the air cleaner, as well as the air cleaner itself. Models are available with one, two or four sensing units with a single signal box for engines with single or multiple air inlets.

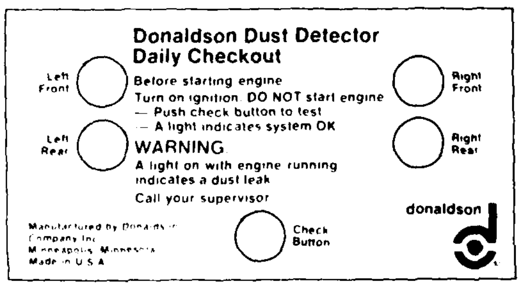
Complete Kits

Complete Donaldson Dust Detector Kits	
DDX00 4251	Single System 24 Volt D C
DDX00 4252	Dual System 24 Volt D C
DDX00 4254	Quad System 24 Volt D C

Service Parts

Service Part	Part Number
Signal Box, Single System, 24 Volt D C	P12 6082
Signal Box, Dual System, 24 Volt D C	P12 6084
Signal Box, Quad System, 24 Volt D C	P12 6085
Dust Sensor (Replace with each Air Cleaner Element change)	P12 6088
Cable Assembly, 15 feet, Type SJT	P12 6086
Switch-Sensor Housing Assembly	P12 6089
Switch-Sensor Housing Gasket	P12 6090
Venturi Assembly	P12 8449
Venturi Gasket	P12 6091
F[illegible]e	SFE 9 (Available locally)

Decal pictured is affixed to each signal box. It is important that operators are familiar with the Daily Checkout and Warning Instructions indicated on this decal.



For proper installation, proceed as follows:

1

The best location for the Donaldson Dust Detector venturi and switch is in the bottom of a straight duct just ahead of the intake manifold or turbocharger inlet. A straight section, at least 7.25" long, is required for installation. The minimum duct inside diameter is 3.88". See Figure 1

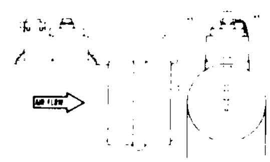


Fig. 2

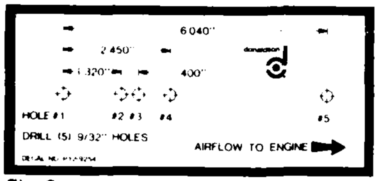


Fig. 3

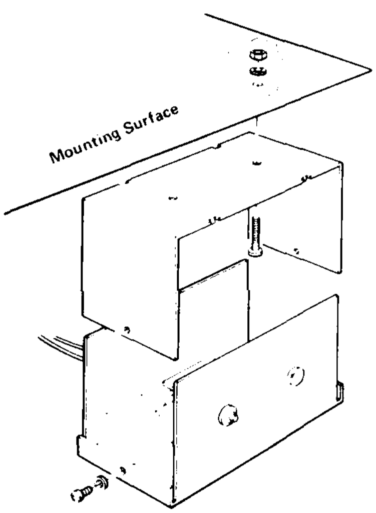


Fig. 4

2

If it is necessary to place the venturi and switch housing immediately downstream of a bend in the intake duct, the unit should be mounted on the outside of the bend. See Figure 2.

3

Five mounting holes are required in the duct wall as shown on template provided. See Figure 3. Place template in actual mounting location of the Dust Detector. Carefully center-punch and drill hole size according to template. Remove template. Clean the inside of the duct carefully to protect the engine from damage.

4

Place pressure-sensitive gasket, P12-6091, on venturi after removing paper backing. The venturi is placed inside the duct over the five closely spaced holes, large end toward engine intake. Use a 1/4-28 x .75 in. bolt in hole No. 4. Engage the internal nut in the venturi assembly and tighten bolt securely using a 3/16" allen wrench, keeping the pump in line with the other holes. The internal nut is a deformed thread locknut and the bolt will turn somewhat hard. Maintaining alignment can be done by using a 1/4-28 x 1.5 in. bolt in hole No. 1 temporarily. *NOTE: Be sure to remove bolt from hole No. 1.*

5

Check air passages in protruding bosses of the switch housing. The air passages should be clear of obstruction. Align gasket on switch-sensor housing. Place the switch housing over the end holes, Nos. 1 and 5, large end toward engine intake. The bosses will fit through the two closely spaced holes and into the pump assembly. Place the 1/4-28 x 1.5 in. socket head bolt in hole No. 1 and engage the captivated nut in the pump assembly. Place the second 1/4-28 x 1.5 in. socket head bolt in hole No. 5 and engage the second captivated nut. Pull both tight. Make certain the P12-6088 Rubber Dust Sensor is installed and the service cover latched.

6

The 1/4-28 x 1.5 in. and .75 in. long bolts supplied with the kits are for use with ducts up to .10 inches thick. Use 1/4-28 x 1.75 in. and 1.0 in. bolts (not supplied) for ducts from .10 in. to .35 in. thick.

7

Connect cable to switch housing receptacle. Route and secure cable along frame members etc. into cab. *CAUTION: Avoid exhaust pipes and other heat sources.*

8

Mount signal box in an available location in the cab, visible to operator (Figure 4). The signal box cover should be removed from the signal box prior to mounting. Heads of mounting bolts must be inside the box to avoid interference with internal components. Reassemble signal box. The paired leads from the signal box come with butt end connectors assembled to them. Place the cable wires in pairs in the connectors and crimp tightly. Connect wires: black to black and white to white. The signal box housing must be grounded either by mounting bolts or by adding an additional grounding wire. *NOTE: When installing dual or quad systems, connect paired leads as indicated on the marking*

9

Connect the power lead with the fuse as close as possible to any terminal on the vehicle electrical system that is energized when the engine is running, and dead when the engine is stopped (such as the accessory side of the accessory switch). Proceed to Installation Checkout.

Installation Checkout

Before your Donaldson Dust Detector is put into service, please check these points:

1. Turn on accessory circuit that powers the Dust Detector system.

2. Push test button on front of signal box. The signal light(s) should come on and remain on until the test button is released. If so, your system is operational.

3. No light: If the light does not come on, proceed to No. 3 of the Trouble Shooting Guide. After correcting the problem, repeat No. 2.

4. If light is on without pushing the test button, proceed to No. 2 of the Trouble Shooting Guide. After correcting the problem, repeat No. 2.

Trouble Shooting Guide

	Symptom	Cause	Remedy
1	Light comes on with engine at high idle or full load and goes off with engine stopped and circuit energized.	Gross Dust Leak	Visually check the intake system for damage, bent air cleaner, broken or damaged pipes, split or loose hose connections, etc. If the reason for dust entry is not determined by these checks, it will be necessary to disassemble the air intake system and visually check for leaks from the clean air side of the element back to the turbocharger or engine inlet. Because most leaks found by this device are small in size, it is imperative to check the inlet components with extreme care. Most of the time dust streaks will indicate the point of entry. After the cause of the leak is found and corrected, the entire intake system must be carefully cleaned to remove any residual dust that could cause an additional leak indication by the Dust Detector. Install a new dust sensor.
2	Light comes on with system energized but engine not running. Note: The Donaldson Dust Detector utilizes a normally closed circuit as a fail-safe feature. Any break in the circuit will cause the light to come on when the system is energized.	a. Dust sensor not in socket b. Cover not closed and latched c. Disconnected cable, broken cable or connectors, defective switch housing, defective light box.	a. Push sensor in firmly b. Close and latch cover c. Check to see that cable is connected at switch housing. If the light is on and the cable appears to be correctly installed—to determine the problem area, disconnect cable at the switch housing. Insert a U shaped connector in the two holes in the plug end of the cable as shown in Figure 5. With the cable shorted in this manner, a light out indicates a defective switch housing. Replace switch housing. If the light remains on with the cable shorted, the problem is a defective cable or light box. Cut the cable at the light box side of the butt connectors. Short the leads together. If the light goes out, the cable is defective. Replace the defective cable. If the light remains on, the light box is defective. Replace light box.
3	Light does not come on when test button is pushed.	a. No power to Dust Detector b. Bad connection in box c. Defective light or resistor	a. Check and correct power at fused lead connection, fuse in fuseholder or broken power lead wire. Signal Box not grounded b. Check and repair wiring in signal box c. Replace signal box
4	Light on at idle, but goes out at high idle or full load	a. Faulty switch housing	a. Replace switch housing

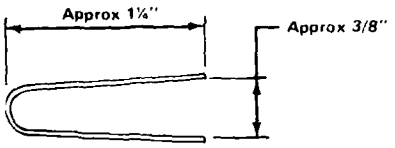
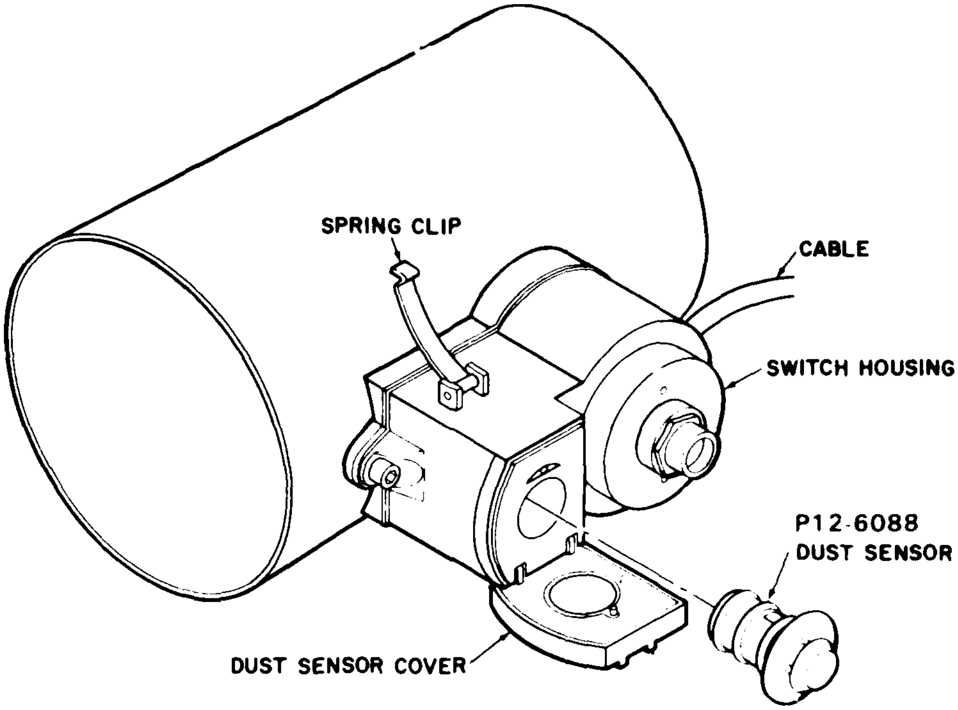


Fig. 5 **18 or 16 gauge solid wire**

Donaldson Dust Detector Service Instructions



The Donaldson Dust Detector is energized at all times during engine operation. **IT IS MANDATORY THAT THE DUST SENSOR PART NO. P12-6088 BE REPLACED AT EACH ELEMENT CHANGE.**

To replace the P12-6088 Dust Sensor:

1. Shut engine off.
2. Remove accumulated dust on and around the outside of the dust sensor cover before opening.
3. Withdraw the dust sensor by pulling and twisting slightly being careful not to spill any dirt into the receptacle.
4. Install a new sensor by pushing firmly until it reaches the bottom of the receptacle. Close and latch cover. NOTE: The sensor will not allow the cover to close completely unless it is properly seated.
5. Be sure to check your system:
   a. Turn on accessory circuit that powers the Dust Detector system.
   b. Push test button on front of signal box. The signal light should come on and remain on until the test button is released. If so, your system is operational.
6. If light remains on refer to trouble shooting guide.

Complete Kits

Complete Donaldson Dust Detector Kits	
DDX00-4251	Single System 24 [illegible]
DDX00-4252	Dual System 24 [illegible]
DDX00-4254	Quad System 24 [illegible]

Service Parts

Service Part	Part Number
Signal Box, Single System, 24 Volt D.C.	P12 6082
Signal Box, Dual System, 24 Volt D.C.	P12 6084
Signal Box, Quad System, 24 Volt D.C.	P12 6085
Dust Sensor (Replace with each Air Cleaner Element change)	P12 6088
Cable Assembly, 15 feet, Type SJT	P12 6086
Switch-Sensor Housing Assembly	P12 6089
Switch-Sensor Housing Gasket	P12-6090
Venturi Assembly	P12 8449
Venturi Gasket	P12 6091
Fuse	SFE 9 (Available locally)

donaldson

Donaldson Company, Inc.
1400 West 94th Street
Minneapolis, Minnesota

Mailing Address
Box 1299
Minneapolis, Minnesota 55440

APPENDIX B

TECHNICAL DATA - NORTHERN INSTRUMENTS LUBE-SAFE ANALYZER

(BLANK)

LIMITED WARRANTY

NORTHERN INSTRUMENTS CORPORATION hereafter referred to as NORTHERN warrants that LUBE SAFE will be free from defects in parts and workmanship for a period of one year from date of purchase when used as instructed in the manual furnished with the instrument. This warranty does not extend to instruments which have been subjected to misuse, neglect or accident. Any attempt to open the sealed unit or make any adjustments not covered in the manual will void the warranty.

THIS WARRANTY IS IN LIEU OF ALL OTHER WARRANTIES EXPRESSED OR IMPLIED INCLUDING WARRANTIES OF MERCHANTABILITY AND FITNESS FOR PURPOSE. ANTICIPATED PROFITS, LOSS OF TIME, CONSEQUENTIAL DAMAGES OR OTHER LOSSES INCURRED BY THE USER IN CONNECTION WITH THE USE OF THIS INSTRUMENT.

NORTHERN's liability under this warranty shall be limited to the repair or replacement of any part or parts thereof which proves, upon NORTHERN's examination, to be defective within the one year warranty period from date of purchase.

After the one year warranty period any repairs to the instrument will be charged to the user on the basis of [illegible] components and labor required.

NORTHERN reserves the right to make changes in the design or construction of this instrument at anytime without incurring any obligation to make any change whatever to units previously sold or delivered.

All service will be performed at the factory. Instruments requiring service must be carefully packed and shipped prepaid to the address noted below.

N.I.C. NORTHERN INSTRUMENTS CORP.
6680 N. HIGHWAY 49 LINO LAKES MINNESOTA 55014
PHONE 612 784 1250 TELEX 290 431

Operating Manual

Lube Safe
OIL QUALITY ANALYZER

FOREWORD

Oil is subjected to high temperature and extreme pressures during engine operation. An atmosphere conducive to oxidation is usually present in the crankcase. A variety of contaminants enter the oil system. While some contaminants are inert, others are chemically active or cause undesirable chemical reactions. The physical and electro chemical properties of the oil change during use and it is this change that is important and affects the lubricating capability of the oil. For this reason an analysis of the new (unused) and used oil should be conducted frequently to determine their relative conditions. This is ascertained by evaluating the changes in physical and electro chemical properties. The interpretation of these changes, as they affect engine performance, is of fundamental significance. ONE IMPORTANT AND FUNDAMENTAL ELECTRO CHEMICAL PROPERTY OF OIL IS ITS DIELECTRIC CONSTANT.

LUBE SAFE detects, measures and reports the TOTAL EFFECT of contamination on the dielectric constant of oil. By doing so, LUBE-SAFE makes it possible to determine when oil is still usable, thus permitting longer intervals between changes. Even more importantly, overhauls can be postponed by detection of impending lubrication or mechanical failure.

Further, the sensor and operating range of LUBE SAFE has been designed to deal specifically with the current swing to longer oil drain intervals, which have resulted from engine and filter refinements and increased use of synthesized oils.

Northern Instruments Corporation is a manufacturer of unique, proprietary products developed from our technological base, which is thin film chemistry. The term "thin film" as used here, refers to research into the behavior and functioning of molecules in very thin layers. The sensor in LUBE SAFE owes its accuracy and sensitivity to this research.

GENERAL INFORMATION

1. There are hundreds of oils on the market processed for specific lubrication purposes. The dielectric constant of these oils can vary between brands and types. This need not have anything to do with the quality of a particular oil processed for a specific purpose - it simply means that different types of oil additives (or their lack) will result in dielectric constant variations in oil.

For this reason leading users of oil recommend that the interpretation of an analysis is, in part, a comparison between the properties of the unused oil and the properties of the used oil. To accommodate this, LUBE-SAFE has been designed to be calibrated quickly and easily to a zero reference with the same brand and type of oil in an unused state as the used oil to be tested.

2. As the sensor is sensitive to moisture, do not operate LUBE-SAFE in rain, snow or fog.

3. If LUBE-SAFE is subjected to significant temperature changes (for example, from 45° F. to 75° F.) then recalibrate the instrument as close as possible to the extremes of the range.

4. Always clean the sensor cavity thoroughly.

5. When testing make it a practice to fill the oil sensor cavity to the top every time.

6. While it is possible to obtain an oil sample from the engine's dipstick, it is strongly recommended that our SAMPULLER (order card enclosed) be used for sampling purposes. Dipstick samples can be contaminated with moisture or other misleading contaminants. SAMPULLER allows the user to obtain excellently representative samples at any crankcase level.

7. LUBE-SAFE is as ruggedly constructed as it can be and remain the sensitive instrument it is; however, please treat it with reasonable care.

OPERATING FEATURES

1 Oil Status Indicator
Visually indicates the status of oil test sample, as compared to the calibration oil sample

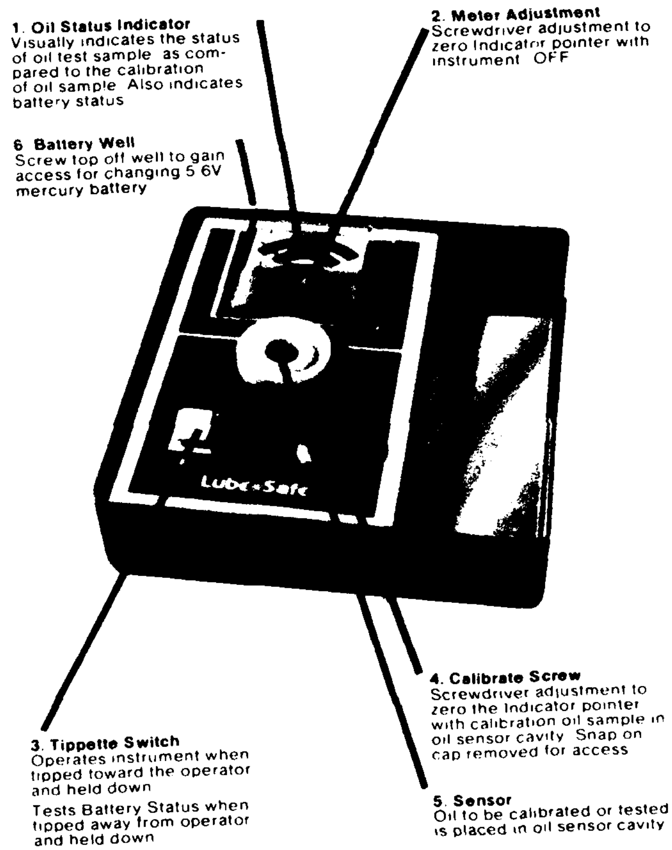
2 Meter Adjustment
Screwdriver adjustment which will zero Indicator pointer with instrument OFF

3 Tippette Switch
a Operates instrument when tipped toward the operator, the Operate position and held down
b Indicates status of Battery when tipped away from operator the Battery Test position, and held down

4 Calibrate Screw
Screwdriver adjustment which will zero Indicator pointer with calibration oil sample in Oil Sensor cavity Snap on cap removed for access

5 Oil Sensor
Oil to be calibrated or tested is placed in Oil Sensor cavity

6 Battery Well
Holds 5 6V Mercury Battery Screw top off to gain ss to well



OPERATING INSTRUCTIONS

Careful and continued adherence to the few simple directions below will provide the operator with the technique necessary to insure dependable operation

The instructions are broken down into two categories CALIBRATION setting the unit to a zero reference with the same brand and type of oil in an unused state as the used oil to be *tested and TESTING measuring and reporting the change in* the unused oil s dielectric constant

CALIBRATION

1 Tip and hold down Tippette Switch in Battery Test position The pointer must come to rest in the Battery OK zone If not replace battery

2 Wipe Sensor cavity carefully and thoroughly with clean dry tissue or cotton wad

3 Fill the Sensor cavity with new oil of same make and grade as oil to be tested

4 Tip *and hold down* Tippette Switch in Operate Position Zero the pointer of the Oil Status Indicator by turning the Calibrate Screw in either a clockwise or counterclockwise *direction* Release the Tippette Switch

5 Again thoroughly clean the Sensor cavity The instrument is now calibrated and ready for testing used oil Recalibration **should not be** *necessary unless the unit is* **subjected to significant humidity or temperature changes, although it is a good practice** to recheck calibration periodically during testing

TESTING

1 Always start with a clean Sensor cavity Fill the Sensor cavity with used oil to be tested

2 Press and hold down the Tippette Switch in Operate Position for 10 to 15 seconds and observe the Indicator pointer The rationale for the pause is **explained in the next section**

3 The color of the zone in which the Indicator pointer comes *to rest indicates the oil s condition*

a The lower scale (petroleum) is used for petroleum based oils (recommended oil changes of up to 7 500 miles

b *The upper scale* (synthetic) is used for synthesized oils recommended oil changes at 15,000 miles and higher

4 If the Indicator pointer comes to rest in the green zone the *oil is still satisfactory If the pointer comes to rest in a red zone* the oil is contaminated enough to be changed The further into the red zone the pointer moves the greater the contamination

5 Clean the Sensor *cavity and proceed to the next test sample*

See the following section Technical Information for useful interpretations which can be made through experience with the instrument

TECHNICAL INFORMATION

LUBE SAFE measures oil quality by sensing a property of oil called the dielectric constant The dielectric constant increases or decreases in proportion to the type and relative concentration of the contaminants present in an oil system

1 Oxidation and acids build up with engine running time and are the primary degradation products in engine lubricating oils and thus are considered as Normal Contaminants

TECHNICAL INFORMATION

2 Sludge Dirt Fuel Soot Water Anti Freeze Metal Particles and Gasoline are other contaminants encountered which are or are not present depending on the health of the lubricating system

3 Fortunately the more potentially catastrophic of these contaminants i e Water Anti Freeze Metal Particles and Gasoline *are readily* distinguishable

a Water and Anti Freeze traces cause the Indicator pointer to drift persistently to the right or to peg immediately

b The presence of Metal Particles will cause a similar reaction although the pointer movement will generally be more erratic and jerky as it moves to the right as the particles settle to the bottom of the Sensor cavity

It is in order to observe these types of reactions that we request the Operate Switch to be held down for 10 to 15 seconds

4 The effect of Gasoline contamination is unique in that it is the only one that causes a decrease in the dielectric constant All the other contaminants have a positive effect We already know that an oil s dielectric constant changes in proportion to the type and concentration of contaminants present in the oil

As a result

a The unit s Indicator pointer will come to rest in the rejection zone to the left of 0 when gasoline is present in sufficient quantity to overcome the contaminants in the oil that cause an increase in the dielectric constant

b The optimum time to detect Gasoline would be when the oil was as slightly used as possible

c The Gasoline contamination could cancel out the normal expected gradual increase in the dielectric constant as the dilution increases In other words the unit gives the same or lower reading test after test after test instead of gradually increasing

5 LUBE SAFE s red or oil rejection zones reflect our experience with correlated laboratory tests for a safe rejection threshold for standard petroleum based multi viscosity and univiscosity oils and the new long drain synthesized oils We stress that this is a suggested threshold Some users based on their own operating criteria and laboratory analysis may decide to change oil further into the Rejection Zone They certainly have this option

6 Following an oil change especially with detergent oils a test may show the pointer slightly in the left hand rejection zone for the first 500 miles thereafter tests will show pointer movement to the right This is attributable to the action of the additives in the new oil

MAINTENANCE

LUBE SAFE requires very little maintenance Thorough cleaning of the sensor after testing is of course a must If oil is spilled on the instrument s face it should be wiped off promptly Should the instrument be dropped or bumped hard it is advisable to recheck the calibration

The power source for LUBE SAFE is a 5 6V mercury battery which is available from our Customer Service Department

To change the battery simply use a coin to remove the cap from the battery well and replace the old battery with the new battery making sure that the positive (+) end of the battery enters the well first

WARRANTY AND SERVICE

LUBE SAFE is warranted against defects in materials and workmanship for a period of one year from date of purchase All service on LUBE SAFE will be performed at the factory

APPENDIX C

AIR-BITE TEST PLAN AND PROCEDURE

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AIR-BITE TEST PLAN
for
Fort Hood, Texas

Purpose

To investigate and generate data demonstrating the capability of commercially available Built-In Test Equipment (BITE) instrument for monitoring the air entering the operating engine and detection of the presence of dirt.

Scope

The commercial device to be evaluated during this program is the Donaldson Dust Detector, an instrument that will signal the operator when the concentration of dust exceeds the level expected for a properly functioning air filter system so that corrective action can be taken.

Points of Contact

Hq III Corps & Ft. Hood - Maj. Russell C. Dougherty, G-4
Tel (817) 685-6439

Maintenance Division - LTC James D. Greear, DIO
Tel (817) 658-2208

1st Cavalry Division, 2/5th Cavalry - 1LT Robert Kocher, BMO
Tel (817) 685-4043

2nd Armored Division, 2/58th Infantry, 1LT Cornelius A. Banister, BMO
Tel (817) 685-3734

SwRI - Mr. John D. Tosh - Supervisor, Field Operations
Tel (512) 684-5111, ext. 2576

SwRI - Mr. R.A. Alvarez - Fleet Monitor
Tel (512) 684-5111, ext. 3264

Ft. Hood Oil Analysis Laboratory - Mr. Norm Smith, Chief
Tel (817) 685-2909

Responsibilities

The G-4 Office, Hq III Corps & Ft. Hood will be the central contact point between SwRI, DIO, 2/5th Cavalry and 2/58th Infantry. All matters pertaining to the evaluation of the Donaldson Dust Detector will be coordinated through Major Daugherty, III Corps G-4.

DIO Maintenance is responsible for all repairs, installation or removal of the Donaldson Dust Detectors. All work to be performed on the dust detectors will be coordinated with LTC Greear, Director of Maintenance.

The division G-4's are responsible for overall staff supervision of program as conducted by subordinate units.

The battalion maintenance officers of the 1st Cavalry Division, 2/5th Cavalry and 2nd Armored Division, 2/58th Infantry are responsible for care and safe-guarding of the dust detectors and the procedure training of the respective crew members on those vehicles where the Dust Detectors are installed. They will insure that the attached test form is filled out--recording activation events of the dust detectors.

SwRI personnel will provide technical assistance in the collection of all data and will conduct visits on a bi-monthly basis to monitor the program. The SwRI representative will coordinate .th all members involved in the test plan at every visit to Ft. Hood.

The chief of the Oil Analysis Laboratory will be aware of all vehicles involved in the test program and will provide SwRI with a copy of DD Form 2027 (Oil Analysis Record) on all samples processed on the test vehicles.

AIR-BITE TEST PROCEDURES

PRIOR TO STARTING THE ENGINE, THE OPERATOR WILL PERFORM THE FOLLOWING PROCEDURES:

1. Turn on accessory circuit that powers the Dust Detector System.

2. Push test button located on the front of the signal box. The light(s) should come on and remain on until the test button is released.

3. If the light is on without pushing the test button, notify the battalion maintenance officer or his representative. Once the problem is corrected, proceed with Step No. 2.

NOTE: The Donaldson Dust Detector utilizes a closed circuit as a fail-safe feature. Any breaks in the circuit will cause the light to come on when the system is energized.

IF THE SIGNAL LIGHT SHOULD COME ON WHILE THE ENGINE IS RUNNING, THE OPERATOR WILL PERFORM THE FOLLOWING PROCEDURES:

1. Visually check the air intake system for damage, bent air cleaner, broken or damaged pipes, split or loose hose connections and clogged air filter elements. If the reason for dust entry is not determined by these checks, notify the battalion maintenance officer or his representative.

NOTE: Once the cause of the leak is found and corrected, the entire intake system must be carefully cleaned to remove any residual dust that could cause an additional leak indication by the dust detector.

2. An engine oil sample will be taken and sent to the oil analysis laboratory. The label on the oil sample will be filled out in accordance with existing policy.

3. Test Form No. 1 will be filled out and submitted to the battalion maintenance officer.

4. A new dust sensor will be installed. To replace the dust sensor:

   a. Shut engine off.

   b. Remove accumulated dust on and around the outside of the dust sensor cover before opening.

   c. Withdraw the dust sensor by pulling and twisting slightly, being careful not to spill any dirt into the sensor receptacle.

   d. Install a new sensor by pushing firmly until it reaches the bottom of the receptacle. Close the latch cover. The sensor will not allow the cover to close completely unless it is properly seated.

NOTE: It is mandatory that the dust sensor be replaced at each air filter element change.

FT. HOOD - DUST DETECTOR TEST PROGRAM

Bumper No. Type Vehicle Vehicle S/N Engine S/N

DATE DUST DETECTOR LIGHT ACTIVATED	ODOMETER MILEAGE READING	HOUR METER READING	DATE OIL SAMPLE SUBMITTED TO AOAP LAB	WAS NEW SENSOR INSTALLED?	CORRECTIVE ACTION REQUIRED

Test Form No. 1

APPENDIX D

DA FORM 3254-R OIL ANALYSIS RECOMMENDATION

(BLANK)

OIL ANALYSIS RECOMMENDATION AND FEEDBACK of this form, see TB 43-0106 and TB 43-0210, the proponent agency is DARCOM.	REQUIREMENT CONTROL SYMBOL CSGLD—1818
1. FIELD (Include ZIP Code and Telephone Number) 2/8 ARMOR, 1CD Bldg. #30017 Ft. Hood Texas	3. LAB RECOMMENDATION NUMBER 80-128 4. END ITEM MODEL M60A1 5. END ITEM SERIAL NUMBER 5436 (C-36)
2. FROM: LABORATORY (Include ZIP Code) Ft. Hood Oil Lab Bldg. #7012 Ft. Hood, Texas	6. COMPONENT TYPE Engine 7. COMPONENT SERIAL NUMBER A0856 8. COMPONENT TIME (Hours/Miles) Unknown

9. RECOMMENDATION AND REASON FOR ACTION

Evaluate component for serviceability. Suspect piston ring,piston, and cylinder wear. Suspect faulty induction system. Report findings and/or parts used for repair of component to this lab; utilizing reverse side of this form, if necessary. From December of 1979 throught July 1980 there were 6 Recommendations made to check out the induction system and correct the faults. In July 1980, Stas Personnel found both air boxes did not seal properly. Recommended that Left Air Box Door be replaced.

10. SIGNATURE AND TITLE OF INITIATOR	11. DATE (Day-Month-Year)
B Carraway B CARRAWAY/ASST LAB CHIEF	8 September 1980
12. NOTE FOR ARMY AVIATION ONLY: Equipment Improvement Recommendation (EIR), DA Form 2407, will be submitted when maintenance is performed due to impending or incipient failure indicated by oil analysis, Failure Code 916.	13. EIR NUMBER

14. FEEDBACK (Maintenance Performed/Action Taken)

15. FROM: FIELD/DEPOT MAINTENANCE PERSONNEL	16. DATE (Day-Month-Year)
TO: LABORATORY	NOTE FOR ARMY AVIATION ONLY: Copy of this form with DA Form 2407 (EIR) attached will be sent to: Commander, TSARCOM Attn: DRSTS-QEP(2) 4300 Goodfellow Blvd. St. Louis, MO 63120

DA FORM 1 JUN 78 3254-R EDITION OF 1 OCT 73 IS OBSOLETE

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APPENDIX E

FH FORM 597, REPAIR DATA SHEET

SERVICEABLE
NOV 5 1980

REPAIR DATA SHEET
(AR 760-1)

DATE OCT 2 1980
(Repair/Overhaul Date)

GENERAL

Family/Item M60 ENGINE 1790-2D SN A0856

Job Number 10016 FSN 2815-00-410-1204

Last Overhauled by ANAD

Date 4-78 Hr Meter Reading 295

AOAP

Received due to AOAP YES ✓ NO

What was AOAP diagnosis?

Was AOAP diagnosis correct? YES ✓ NO

Which parts of AOAP diagnosis were beyond the wear limits? Rings - Rod Bearings - Main Bearings - Eng. Cylinders - Pistons

Other parts beyond wear limits Crankshaft.

OTHER

SERVICEABLE
1980

Type of failure (Check One):

Lubrication ✓ Handling Air Induction ✓

Storage Cannabalized Improper Installation

Case/Parts broken Cooling System

Other (List) 2ea. cylinder studs broken. Rings broken on one piston.

Your opinion of failure cause/or contributing factor Faulty air induction system. Improper oil change intervals.

(Crew Maintenance)

Mechanic Signature [signature] Foreman Signature J.A. McBride

FH FORM AUG 77 597 (MNT)

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APPENDIX F

OIL-BITE TEST PLAN AND PROCEDURE

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OIL-BITE FIELD TEST PLAN
for
Fort Hood, Texas

Purpose

The purpose of this program is to investigate the capability of a commercially-available Built-In Test Equipment (BITE) instrument for monitoring engine oil condition in support of the Army's Oil Analysis Program.

Scope

The commercial device to be evaluated during this program is an instrument capable of measuring the dielectric constant of lubricating oils and giving a GO/NO-GO indication of potential oil distress which would be followed up with further clarification of oil usability by the AOAP laboratory. This field test project has been established to determine the feasibility of testing the condition of crankcase oil for combat vehicles on oil quality criteria rather than mile/hour intervals.

Point of Contact

Fort Hood

The Fort Hood G-4, AFZF-GD-M, has indicated their willingness to support the evaluation program. Point of contact is: Captain Tony Beavers, Hq III Corps & Ft. Hood, Attn: AFZF-GD-M, Ft. Hood, TX 76544. Telephone: Autovon 737-7197/6530, Commercial (817) 685-7197/6530.

Southwest Research Institute

SwRI will be conducting the evaluation and will furnish any necessary equipment and instructions. Point of contact is: Mr. John D. Tosh, U.S. Army Fuels & Lubricants Research Laboratory, % Southwest Research Institute, 6220 Culebra Road, San Antonio, TX 78284. Telephone: Commercial (512) 684-5111, ext. 2576.

Responsibilities

Ft. Hood will:

- Identify three (3) organizational motor pools for oil samples to be taken from the crankcase of combat unit vehicles. Approximately 20 vehicles should be identified in each unit.
- Furnish vehicle I.D., (i.e., bumper number, engine serial number).
- Provide a one-quart sample of base lubricant from each company motor pool stock designated to participate in the "Oil-BITE" Field Test Program.
- Provide assistance to SwRI personnel in collecting the crankcase oil samples on a semi-monthly basis.
- Provide liaison support to ensure vehicles are available for oil sampling.

Southwest Research Institute will:

- Provide technical assistance in the following areas:
  - Collect used oil samples on a semi-monthly basis.
  - Conduct analysis using "LUBE-SAFE" analyzer.
  - Record data to correlate with AOAP laboratory results.
  - Deliver used oil samples to AOAP laboratory.
- Provide 4-oz sample bottles to be used in the collection of used engine oil samples.

Period of Field Test

This evaluation will be conducted over a three (3) month period. However, the possibility of extending the evaluation over a long period will be coordinated with Fort Hood personnel prior to end of FY79.

OIL-BITE TEST PROCEDURE

THE FOLLOWING PROCEDURES WILL BE ADHERED TO WHEN USING THE LUBE SAFE ANALYZER:

1. Tip and hold down Tippette Switch in Battery Test position. The pointer must come to rest in the Battery OK zone. If not, replace battery.

2. Wipe Sensor cavity carefully and thoroughly with clean, dry tissue or cotton wad.

3. Fill the Sensor cavity with new oil of same make and grade as oil to be tested.

4. Tip and hold down Tippette Switch in Operate Position. Zero the pointer of the Oil Status Indicator by turning the Calibrate Screw in either a clockwise or counterclockwise direction. Release the Tippette Switch.

5. Again thoroughly clean the Sensor cavity. The instrument is now calibrated and ready for testing used oil. Recalibration should not be necessary unless the unit is subjected to significant humidity or temperature changes, although it is a good practice to recheck calibration periodically during testing.

6. Fill the Sensor cavity with used oil to be tested.

7. Press and hold down the Tippette Switch in Operate Position for 10 to 15 seconds and observe the Indicator pointer.

8. The color of the zone in which the indicator pointer comes to rest indicates the oil's condition.

   a. The lower scale (petroleum) is used for petroleum based oils

   b. The upper scale (synthetic) is used for synthesized oils

9. If the indicator pointer comes to rest in the green zone, the oil is still satisfactory. If the pointer comes to rest in a red zone, the oil is contaminated enough to be changed. The further into the red zone the pointer moves, the greater the contamination.

10. Clean the Sensor cavity and proceed to the next test sample.

<u>NOTE</u>: If a reading of "BAD" is obtained, an oil sample will be submitted to the AOAP Lab for verification prior to changing the oil.

ATE

LME